SCIENCE & TECHNOLOGY OFFICE

MSFC's Advanced Space Propulsion Formulation Task

Lawrence D. Huebner, Harold P. Gerrish,
Joel W. Robinson, and Terry L. Taylor
Marshall Space Flight Center

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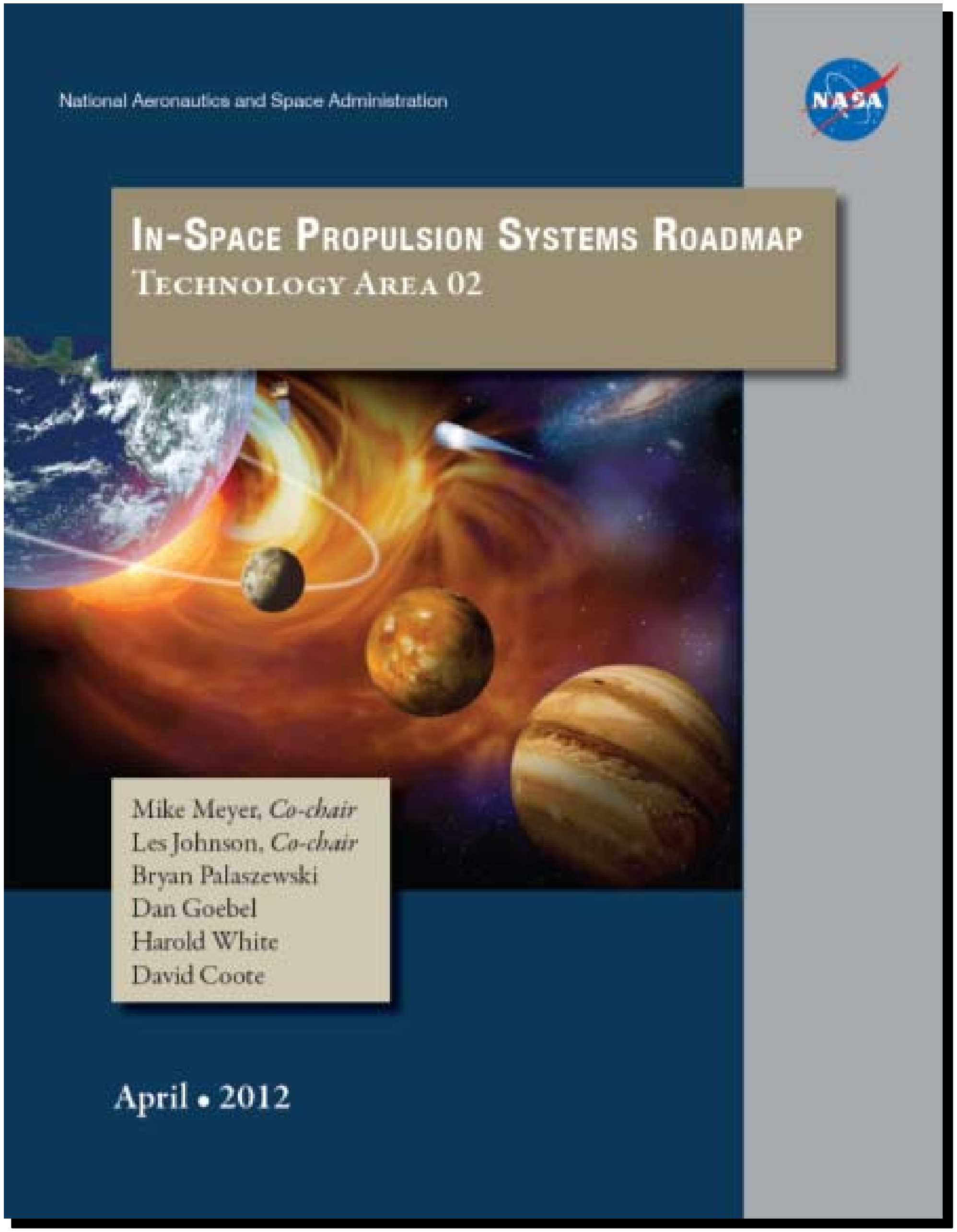
Outline

- Purpose
- Background
- Task Activity
- Sample Results
- Information Access

Formulation Task Purpose

- Provide NASA Space Technology Program (STP) and Office of the Chief Technologist (OCT) with a knowledge base on advanced space propulsion technologies
  - Furnishes next layer of detail for technologies summarized in NASA's In-Space Propulsion Systems Roadmap, Technology Area 02 (TA-02)
  - Supports STP/OCT on where investments should be made
    - Enable good strategic decision making
  - Allows for better utilization of STP/OCT resources by giving context to any past, current, or proposed in-space propulsion technology development efforts in terms of:
    - Performance capability
    - Technology Readiness Level
    - Focus on those with potentially major impacts

Background



- 45 Technologies were identified in NASA's In-Space Propulsion Systems Roadmap, Technology Area 02 (TA-02)
- TA-02 roadmap divided into four basic groups
  - (1) Chemical Propulsion
  - (2) Non-chemical Propulsion
  - (3) Advanced (TRL<3) Propulsion Technologies
  - (4) Supporting Technologies (pertinent technical areas strongly coupled with these groups which could allow significant improvements in performance)
- TA-02 Roadmap limited to 30 pages; more information needed to better understand each concept
- 25 of 45 were studied during this formulation task
  - Emphasis was on groups (3) and (2)

TA-02 Identified Technologies

1.0 Chemical Propulsion
- 1.01 Monopropellants
- 1.02 Bipropellants
- 1.03 High-Energy Propellants
- 1.04 High-Energy Oxidizers
- 1.05 LOX/Methane Cryogenic
- 1.06 LOX/LH2 Cryogenic
- 1.07 Gelled and Metalized-Gelled Propellants
- 1.08 Solid Rocket Propulsion Systems
- 1.09 Hybrid Rockets
- 1.10 Cold Gas/Warm Gas Systems
- 1.11 Solid Micropropulsion
- 1.12 Solid Cold Gas/Warm Gas Micropropulsion Systems
- 1.13 Hydrazine or Hydrogen Peroxide Monopropellant Micropropulsion

2.0 Nonchemical Propulsion
- 2.01 Resistojets
- 2.02 Arcjets
- 2.03 Ion Thrusters
- 2.04 Hall Thrusters
- 2.05 Pulsed Inductive Thrusters
- 2.06 Magnetoplasmadynamic Thrusters
- 2.07 Variable Specific Impulse Magnetoplasma Rocket
- 2.08 Microresistojets
- 2.09 Teflon Microcavity Discharge
- 2.10 Micropulse Plasma
- 2.11 Miniature Ion/Hall

2.0 Nonchemical Propulsion (Continued)
- 2.12 MEMS Electrospray
- 2.13 Solar Sail Propulsion
- 2.14 Solar Thermal
- 2.15 Nuclear Thermal
- 2.16 Electrodynamic Tether
- 2.17 Momentum Exchange Tether

3.0 Advanced Propulsion Technologies
- 3.01 Beamed Energy Propulsion
- 3.02 Electric Sail Propulsion
- 3.03 Fusion Propulsion
- 3.04 Metallic Hydrogen
- 3.05 Atomic Boron/Carbon/Hydrogen
- 3.06 High Nitrogen Compounds (N4+, N5+)
- 3.07 Antimatter Propulsion
- 3.08 Gas Core Fission
- 3.09 Fission Fragment
- 3.10 External Pulsed Plasma Propulsion
- 3.11 Breakthrough Propulsion Physics

4.0 Supporting Technologies
- 4.01 Engine Health Monitoring and Safety
- 4.02 Propellant Storage, Transfer & Gauging
- 4.03 Materials & Manufacturing Technologies
- 4.04 Heat Rejection
- 4.05 Power

TA-02 Identified Technologies

Technologies Addressed in Formulation Task

1.0 Chemical Propulsion
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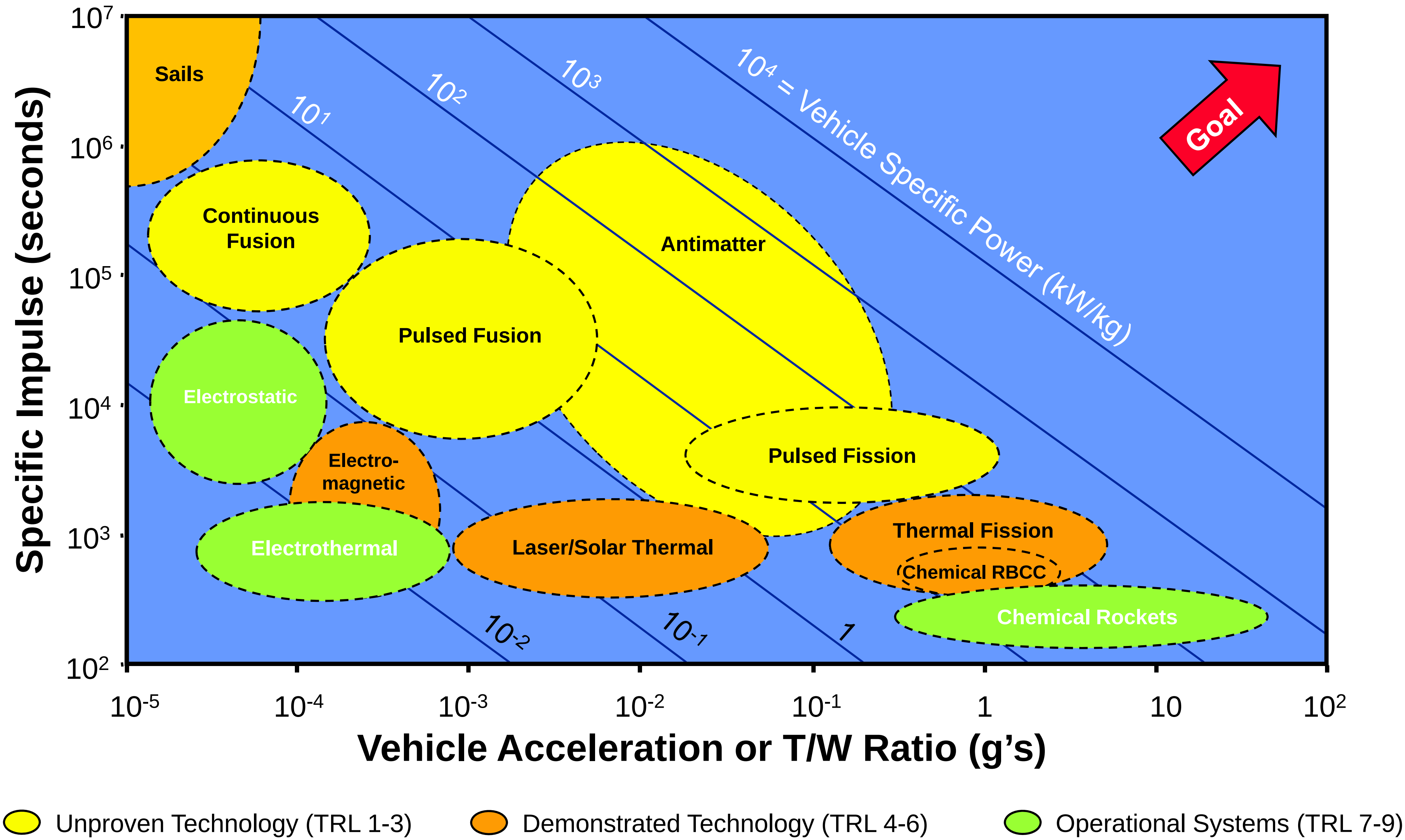
Task Activity

- **Map relevant existing technology and R&D efforts that NASA funds on Space Propulsion Concepts chart to identify gaps**
- **Generate Summary Report and one-page Summary Chart for each technology that includes:**
  - <u>Narrative Description</u> of technology with images depicting concepts and technology current state of the art (laboratory, flight experiments, etc)
  - <u>Mission Applications</u> and/or benefits of using concept compared to existing chemical systems
  - Identification of <u>professional experts</u> (by Name and Organization)
  - Description of <u>past or current efforts</u> at NASA, DoD, and universities
  - Identification of supporting <u>subsystem</u> or component <u>technology</u> <u>hurdles</u> (if applicable) needing development for this propulsion system concept to be feasible
    - Some these may be shared by multiple concepts, increasing its importance
  - Estimate of <u>financial investment</u> with each concept to date (if available)

Space Propulsion Concepts



Mapping of Early FY12 NASA Efforts

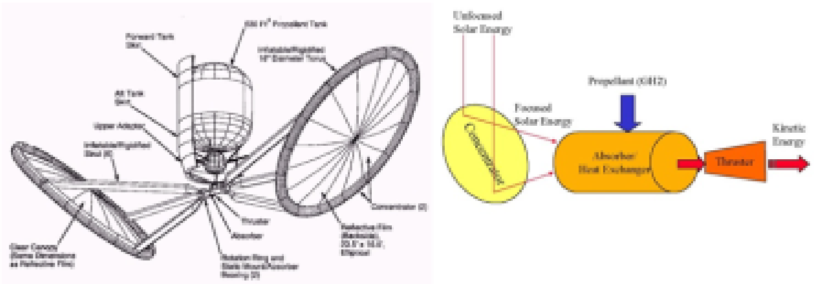
Category/Award	AES	Grants	SBIR	STTR	TDM	NIAC	Other	ISP	*Total*
Chemical Rockets	2	2	2			1		1	8
Chemical RBCC									0
Thermal Fission	1		2						3
Pulsed Fission						1			1
Antimatter			1						1
Laser/Solar Thermal									0
Pulsed Fusion			1						1
Electrothermal			1						1
Electro-Magnetic		4	2	1				1	8
Electrostatic		2	2					2	6
Continuous Fusion			1			2			3
Sails					1	1	2		4

AES: Advanced Exploration Systems
SBIR: Small Business Innovative Research
STTR: Small Business Technology Transfer
TDM: Technology Demonstration Missions
NIAC: NASA Innovative Advanced Concepts
ISP: OCT In-Space Propulsion Project

Sample Summary Chart

Solar Thermal Propulsion (STP)

Propulsion System Description



The STP system takes the unfocused solar energy impinging on a large collector/concentrator and transforms it into kinetic energy of a propellant for thrust from direct heating of the propellant or indirect heating via heat exchanger.

Mission Applications/Benefits (compared with off-shelf chemical)

STP was primarily considered as an upperstage to take payloads from low-earth-orbit (LEO, ~200 miles altitude) to geosynchronous earth orbit (GEO, ~22,000 miles altitude). Having a specific impulse (~900 seconds with hydrogen) about twice that of conventional chemical in-space engines allows for more payload weight on the launch vehicle. However, the volume of liquid hydrogen took up more volume in the payload shroud and the thrust level was 2-4 lbs, meaning the time for a LEO to GEO transfer mission was ~30 days. Others considered STP applications include using the heat from the system as bi-modal for electric power generation and as a transfer stage to the moon and other solar system destinations. More thrust than most electric propulsion concepts.

Subsystem State of the Art

Thruster- Most thruster work in the past involved ground testing indirect solar heating as direct gain or thermal storage. Thrust range 0.5 – 2 lbs, Isp 700-860 seconds with hydrogen. Materials tested Tungsten, Tungsten/Rhenium alloys, Rhenium, Rhenium coated graphite. Experiments with carbides and carbide coatings. Temperature goal 2700-3000K. More testing needed to verify performance holds up to mission requirements.

Concentrator-Inflatable reflectors show the best promise made of polyimide CP to withstand space environment effects. Deployment of 4m x 6m off-axis parabolic inflatable reflector from storage package has been demonstrated to 50-60% efficiency.

Propellant Utilization-Controlled 30 day boil-off of liquid hydrogen to pressure feed the thruster has been demonstrated.

Technical/Development Hurdles

Challenges are optical concentrator accuracy and performance (improving from 50-60% to 85-90%), system/stage packaging, sun pointing (subarcsec accuracy in flat, 1 cm by 1 cm packages), inflatable deployment, controlled cryogenic boil-off, and engine performance. An integrated overall system test has never been performed. Concept TRL~4

STP is limited by payload shroud volume when considering liquid hydrogen LH2. Options to overcome this hurdle include the use of high temperature carbides with melting point ~4200K.

Recommendations

Possible ways for STP to again be considered:

- Increase in Isp above 900 seconds using hydrogen. This requires high temperature carbides with melting points ~4200K. Operating a higher temperature increases the Isp to about 1200 seconds and allows more dissociation of the hydrogen.
- Utilize a liquid hydrogen fuel depot or tanker in orbit to refill a smaller propellant tank or fill deployable tanks.
- Other propellants showing significantly better performance than chemical and better storage than hydrogen.

Subject Matter Experts:

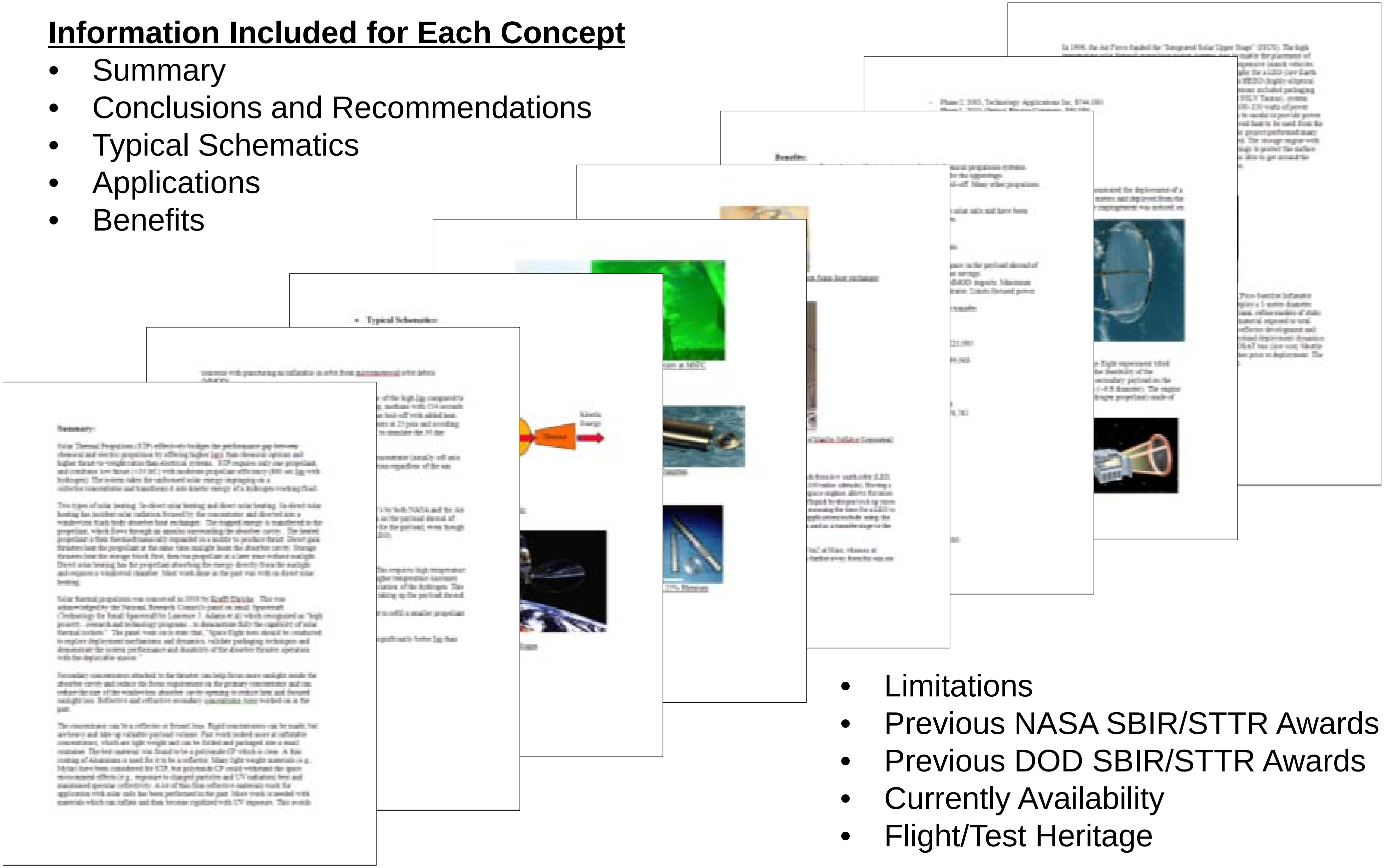
Harold Gerrish (NASA-MSFC)
Mike Holmes (Air Force)

Science & Technology Office

Sample Summary Report

Information Included for Each Concept

- Summary
- Conclusions and Recommendations
- Typical Schematics
- Applications
- Benefits



- Limitations
- Previous NASA SBIR/STTR Awards
- Previous DOD SBIR/STTR Awards
- Currently Availability
- Flight/Test Heritage

Formulation Task Information Access

- Results of this task need wide dissemination
  - Ease of use by STP/OCT
  - Access to interested researchers and Subject Matter Experts
- Plan to utilize a web-based system
  - Examples being investigated:
    - NASA TechPort
    - MSFC Propulsion Databook
  - Allows for easy access, review, and updating
    - "Living" document

Summary

- Formulation task was performed in FY12 to provide additional substance, depth, and activity knowledge to technology areas identified in TA-02, In-Space Propulsion Systems Roadmap
  - 25 of 45 TA-02 Technologies were studied
- Not a complete catalog but attempted to make results objective and factual
- Information is considered in a “draft” state
  - Recommending SMEs and others working in these areas review and provide updates
- Utilize information to develop proposals of promising advanced propulsion technologies

Acknowledgements

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